VOLUME 76 SEPARATE No. 45

PROCEEDINGS

AMERICAN SOCIETY
OF
CIVIL ENGINEERS

November, 1950

COMPREHENSIVE PLAN FOR THE COLUMBIA BASIN

By William Whipple, M. ASCE

WATERWAYS DIVISION

Headquarters of the Society
33 W. 39th St.
New York 18, N.Y.

PRICE $0.50 PER COPY

Published at Prince and Lemon Streets, Lancaster, Pa., by the American Society of Civil Engineers. Editorial and General Offices at 33 West Thirty-ninth Street, New York 18, N. Y. Reprints from this publication may be made on condition that the full title of paper, name of author, page reference, and date of publication by the Society are given.

Proceedings—Vol. 76 November, 1950 Separate No. 45

AMERICAN SOCIETY OF CIVIL ENGINEERS

Founded November 5, 1852

PAPERS

COMPREHENSIVE PLAN FOR THE COLUMBIA BASIN

By William Whipple, Jr.,[1] M. ASCE

Synopsis

A comprehensive plan for the rapidly growing Columbia Basin (in Oregon and Washington), to supplement Grand Coulee, Bonneville, McNary, and other developments, was completed shortly after the disastrous flood of 1948. The planning was done mainly by the Corps of Engineers (United States Department of the Army) and the Bureau of Reclamation (United States Department of the Interior), with the participation of other federal and state agencies through a variety of special arrangements, and with general coordination established through the Columbia Basin Interagency Committee. Congress has authorized the construction of most of the projects recommended. The paper describes the planning process (including formulation of objectives of water resource development), site investigation and selection, over-all basin studies, and reconciliation of conflicting aims in the choice of projects.

The resulting plan is impressive in its magnitude, providing for more than 10,000,000 kw of firm power, 25,000,000 acre-ft of storage usable for flood control, 800 miles of navigable inland waterways, and, ultimately, irrigation of millions of additional acres of land. The over-all mechanical efficiency of the plan is so much better than that of the individual power-producing projects considered singly that a 25% increase in the 2-mill rates established for Bonneville and Grand Coulee dams will pay for the entire power plan, in spite of a doubling of unit construction costs since those projects were built. Requirements of an operation plan are developed, including an adaptation of a forecast basis for obtaining joint use of storage for power and flood control and criteria for unified control of certain elements of the plan, as against advantages of decentralization both functionally and geographically.

Note.—Written comments are invited for publication; the last discussion should be submitted by May 1, 1951.

[1] Col., Corps of Engrs., Washington, D. C.; formerly Dist. Engr., Walla Walla, Wash.

Relationships between the main objectives of water resource development and other related factors, such as conservation of soil and forest cover and measures for the preservation of Columbia River salmon, are discussed.

I. Comprehensive Water Resource Development Needed

The life and economy of the people in the Northwest are much more dependent on sound water resource planning than in most areas of the United States, and these needs are typical of a situation requiring comprehensive

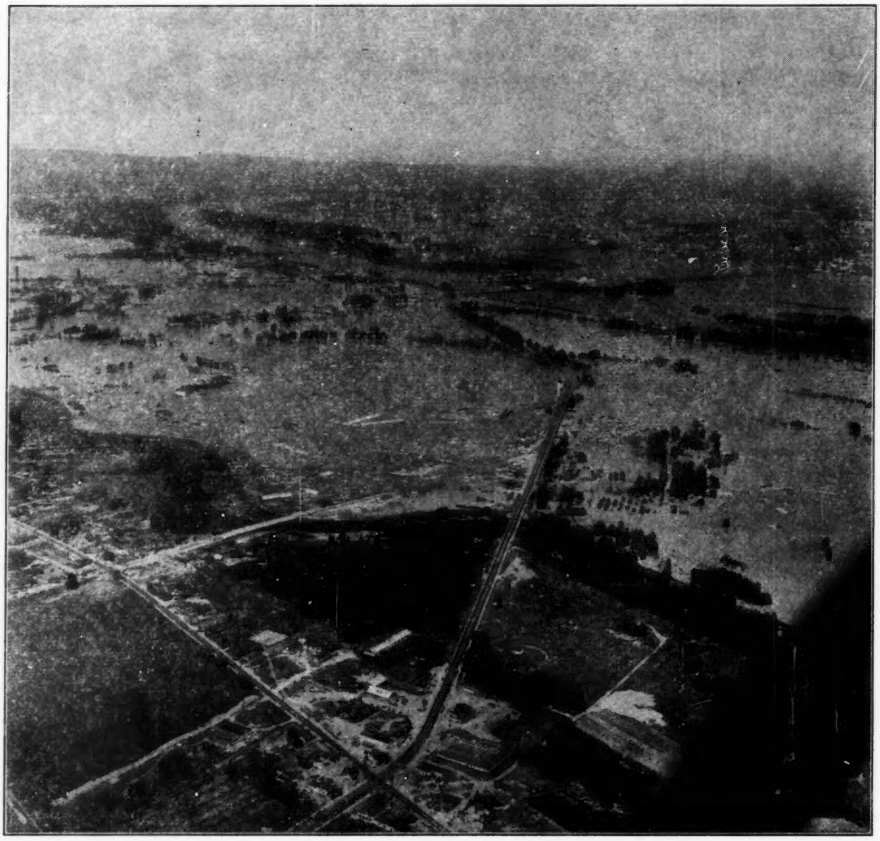

Fig. 1.—Vanport, North Portland, Ore., and Vancouver, Wash., Along the Columbia River During the Flood of 1948

planning. There are now (1950) 4,000,000 acres of irrigated land in the Columbia Basin, with a potentiality for much greater expansion. Damaging floods occur not only locally but also generally, as great catastrophes, like the flood of June, 1948, which cost more than sixty lives and an estimated $102,000,000 in property damage (see Fig. 1). The growth in sales of power,

largely from hydroelectric generation, has been phenomenal; output from Bonneville and Grand Coulee dams, sold at the low 2-mill demand rate, returns more than $20,000,000 annually in cash. This return is sufficient to pay all power costs, including amortization, and return a net annual increment to the United States Treasury greater than $2,000,000 for Bonneville Dam power alone.

On the lower Columbia River commercial navigation is great, and above Bonneville Dam it amounts to more than a million tons annually, despite strong currents and rapids which require towboat power ratios up to ten times those adequate for slack water navigation. Scenic and recreational values of the waterways in this area are outstanding; and the preservation of spawning grounds for the salmon industry is most important. Since these factors are all interrelated, the need for comphehensive planning is apparent.

II. Preparation of the Columbia River Plan

Agency Cooperation.—The new comprehensive plan for the Columbia Basin was initiated in 1943. A congressional directive to the Corps of Engineers (USED) required a general review of the previous comprehensive plan published in 1932. (This was a "308" Report, so called after *House Document No. 308*, which origianlly listed those first authorized.) Other agencies were soon drawn into a general planning effort, which lasted five years. The Bureau of Reclamation (USBR) was especially active, and in 1946 published in tentative form a general plan, popularly known as the "Blue Book," which was of great assistance. This report contained an authoritative survey of irrigation possibilities and allied developments throughout the basin, and a more general treatment of other types of projects.

The planning effort of the USED included an exceptionably widespread and thorough study of major power, flood control, and navigation possibilities, prepared with elaborate procedures for coordination with local interests and other federal agencies, ending in action through the Columbia Basin Interagency Committee (formed from the main federal agencies concerned with water resource development and the governors of the states in the basin). After a review of the USBR findings as to irrigation, the USED accepted them as valid; and after various supplementary studies and the publication of the USED report, the USBR accepted the flood control, navigation, and power projects recommended by the USED.

Thus the final plan is embodied in two reports which supplement one another, each report advocating the same final list of recommended projects. Some of the major projects, particularly the one known as Hell's Canyon, were studied by both agencies, but physical data were pooled. After complete discussion, the comprehensive plan has won general acceptance from all the states and federal agencies concerned.

Reconciliation of Conflicting Views.—The processes of coordination, reconciliation, and, ultimately, choice between various conflicting views are essential parts of the planning process. As tentative plans are explored, various reactions develop, often unexpectedly, and the interests concerned must be convinced of the worth of the plan. The plan itself must be readjusted, or an

irreconcilable divergency will become a disadvantage of that particular project or feature, to be weighed ultimately against its advantages.

During the course of the planning process the USED held numerous public hearings to obtain the views of local interests. Some of these hearings were very lively. Preliminary plans were presented to the public, advantages and disadvantages were discussed, and modifications were made to arrive at a balanced general plan supported by consensus. Flood control is a form of stream development that has been almost uniformly favored by the public,

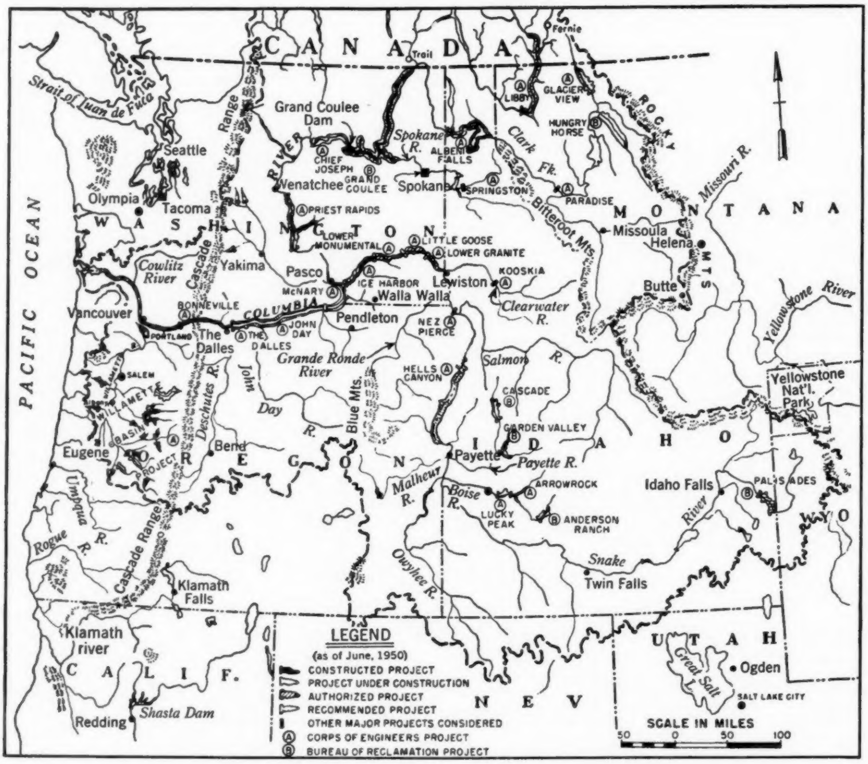

Fig. 2.—Main Control Plan of Columbia River Basin

although interest has varied greatly depending on the number of years since the last flood. Irrigation also has been generally advocated strongly; yet, in some cases, landowners whose lands were being profitably dry-farmed during the current cycle of more abundant rainfall opposed the extension of irrigation. Power projects were opposed in certain areas by private power companies, which maintained that they could meet the local power demand themselves.

Several of the major reservoirs (see Fig. 2) presented some grave local problems and at least potential local opposition. The Glacier View project had to be held in abeyance because it would flood park lands used as winter feeding grounds for wild game; the Boundary and Springston projects were

indefinitely postponed because of local opposition based on commercially important mineral deposits; and the Kooskia and Paradise projects had to be dropped from consideration because of the small towns, farm lands, and communications involved. However, the John Day project won acceptance, in spite of the planned relocation of virtually an entire town, as did the Hell's Canyon project, even though it drowned out an existing power plant.

Unquestionably the most difficult conflict of interests to be resolved lay in the attempt by fishery interests to defer (or, if possible, prevent entirely) all construction of dams on the lower Columbia and lower Snake rivers. Of these, in 1947, Bonneville Dam was constructed; McNary Dam was under way; the four dams on the lower Snake River were authorized; and The Dalles and John Day dams were proposed. All are essential to both the navigation and power plans, and, in addition, John Day will provide much needed flood control. Although the Fish and Wildlife Service (United States Department of the Interior) was cooperating in preparing the report, it was recognized that mutually satisfactory conclusions would be difficult to attain.

Accordingly, the issue was opened to the public through the Columbia Basin Interagency Committee. After a prolonged public hearing and study of all the evidence, the committee recommended unanimously (and the Federal Interagency Committee approved) a finding that the Snake River dams should not be rescheduled, as proposed by the fishery spokesmen, but that The Dalles and John Day dams should be constructed later than the proposed upstream storage projects. Positive measures adopted to conserve the salmon runs are described subsequently.

Development of Specific Plans.—The approach to the preparation of a basin-wide plan was initially decentralized. While general economic studies and power market surveys were being made by arrangement with the Bonneville Power Administration, and other general basin-wide studies were being initiated, the districts of the USED were investigating more than 1,000 dam sites, restudying old data, and otherwise attempting to develop the feasibility and the scope of local or subbasin projects. Especially, it was undertaken to outline pertinent data on major projects that might fit into a general basin plan. Figs. 3 and 4 illustrate difficult conditions of surveying and drilling in some of the more remote sites.

Analysis of the 1946 report of the USBR indicated that, except for financing, irrigation in the Columbia Basin can be regarded generally as a subbasin matter, at least for some time to come. With the exception of Grand Coulee and some irrigation diversions from other projects already authorized, irrigation is not an essential part of the major dams required for flood control, navigation, and power. Such projects as Libby, Hungry Horse, and Hell's Canyon (see Fig. 2) are located where direct irrigation is impractical and the use of their storage for irrigation downstream is unnecessary.

Moreover, the water supply of the Columbia River is so vast relative to the possible use for irrigation that, within the economic life of projects now con-

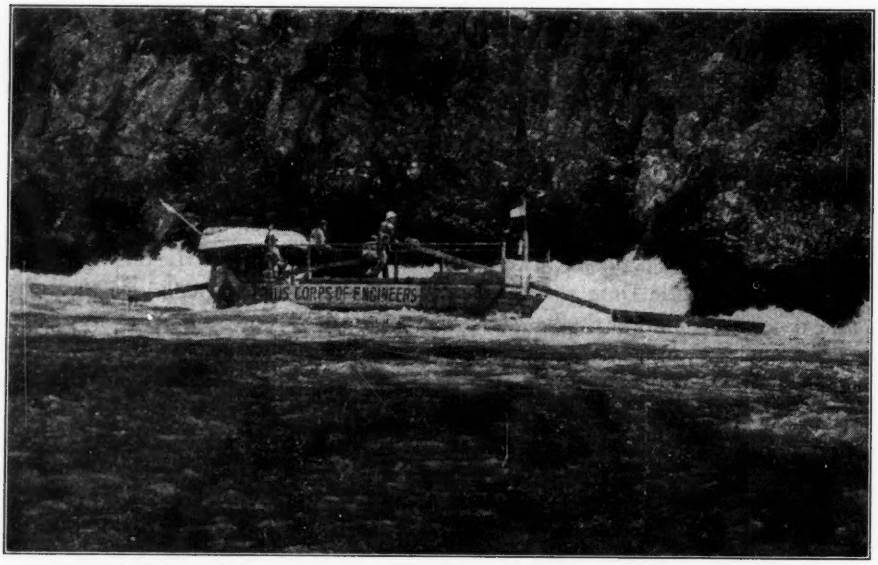

FIG. 3.—SURVEYING IN THE SALMON RIVER, IDAHO; UNITED STATES CORPS OF ENGINEERS

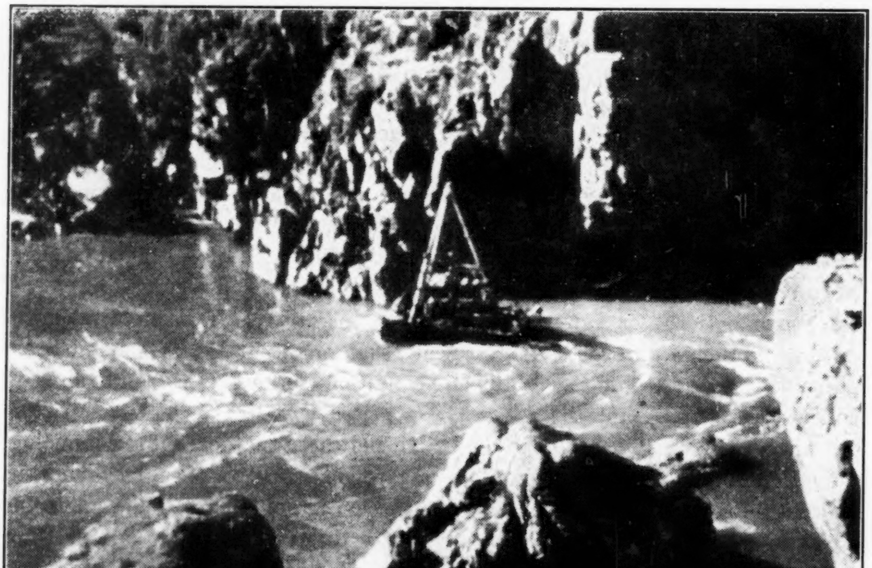

FIG. 4.—DRILL BARGE IN HELL'S CANYON, SNAKE RIVER, IDAHO

sidered, irrigation can be given full priority over all other downstream needs without disadvantage to the recommended federal projects, other than a minor reduction in power output. There remain some difficult questions of water priority within certain subbasins, particularly the upper and middle area of the Snake River Basin; but over-all planning indicates how these conflicts can be laid aside for localized determination entirely in the interests of the subbasins immediately concerned. This conclusion greatly simplified the engineering approach in this basin.

The most apparent general need in the Columbia Basin is for greater production of hydroelectric power. Fig. 5 shows the great growth of power

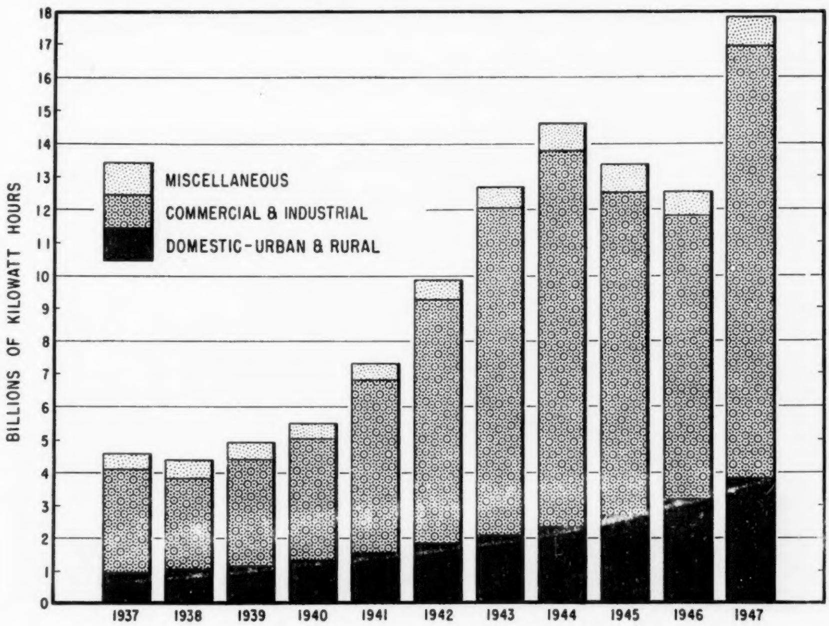

FIG. 5.—SALES OF ELECTRIC ENERGY BY ELECTRIC UTILITIES IN THE PACIFIC NORTHWEST

demand within recent years. Market surveys by the Bonneville Power Administration and the Federal Power Commission indicated that the present production from Grand Coulee and Bonneville dams should be supplemented to insure a system capacity of no less than 10,500,000 kw of firm power at 75% load factor from federal projects some time within the decade 1960–1970. The most rapid load growth within this range of estimates is illustrated in Fig. 6. The more conservative alternate estimate indicates the same total demand, but a date of 1970 for its full development.

No satisfactory alternative energy base of coal or oil exists in this area, and the production of hydroelectric power is relatively inexpensive. The total potential developments of power by irrigation projects (mostly in the Snake

River Valley) and by local flood control projects (mostly in the Willamette Basin) will produce less than half a million kilowatts of firm power. Potential expansion of private and municipal developments is also relatively small if low rates are to continue. The main output of 10,000,000 kw must therefore be provided by the central system of major federal projects, of which Bonneville, Grand Coulee, McNary, Hungry Horse, and Chief Joseph (formerly Foster Creek) (see Fig. 2) are the initial units. Fig. 7 shows the extent of dependance upon the relatively few large projects, and the future load variation during a drought year.

After studying many individual projects and groups of projects, the most advantageous system for power production was found to be a series of run-of-

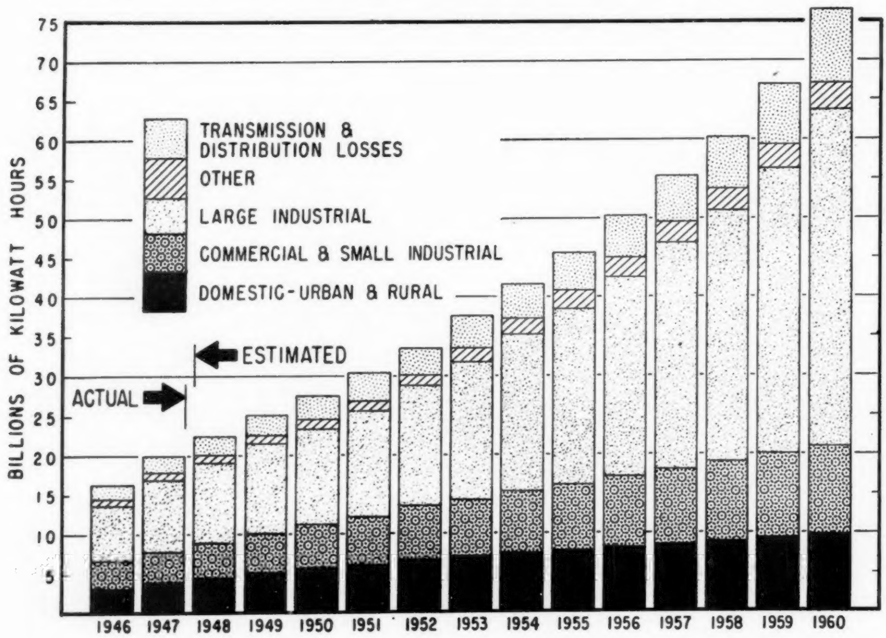

Fig. 6.—Electric Power Requirements in the Pacific Northwest by Major Class of Customer

the-river dams on the main Columbia and lower Snake rivers, with very large storage reservoirs above them to "firm up" power during winter months and drought periods. In such a system, balance is essential. Consecutive run-of-the-river dams added to the system supplement one another indefinitely in proportion to their head. The new storage dams, however, will supplement the run-of-the-river dams in accordance with a law of diminishing returns. The first 10,000,000 acre-ft of storage to be added will be highly productive, provided the run-of-the-river dams are all built. The second 10,000,000 acre-ft will be about two thirds as productive as the first; but the next 20,000,000 acre-ft thereafter would only add as much as the second 10,000,000—and adding another 50,000,000 acre-ft would produce a still smaller increment.

These values are approximate, but they indicate the rapidly decreasing economy of extremely large storage increments. Ultimately, additional storage projects would provide practically no system benefits except for power produced at those sites. One of the interesting side lights resulting from this interrelationship of storage projects is that it is highly misleading to evaluate the economic feasibility of storage projects in terms of a definite order of construction. In one case, the indicated economic power benefits of a given storage project would be more than doubled if considered as constructed first

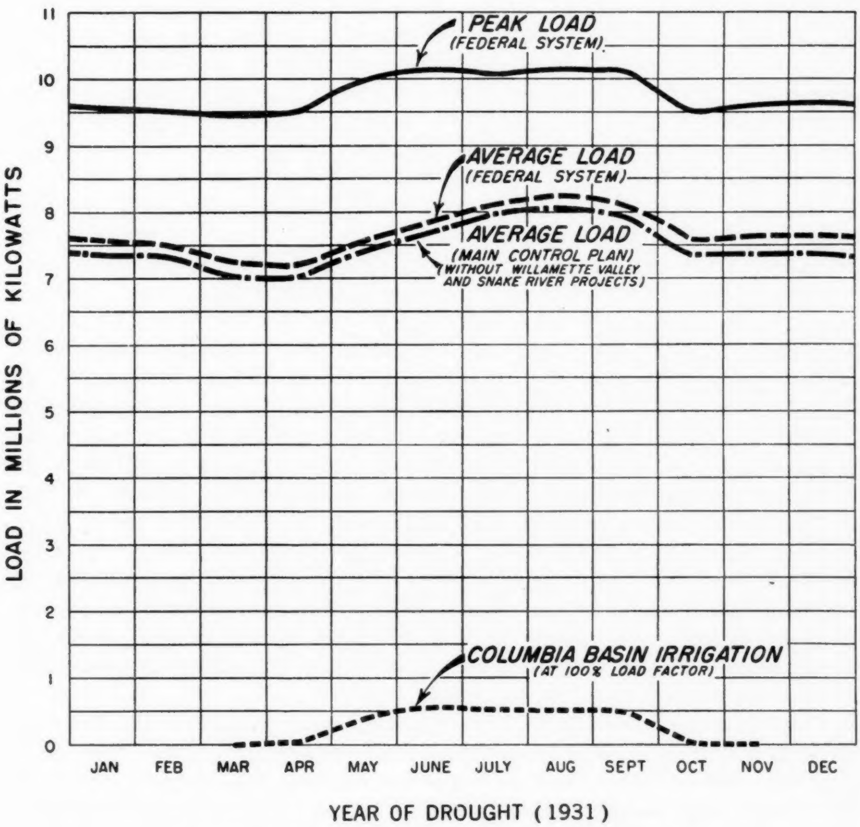

Fig. 7.—Estimated Loads for Major Projects; Phase C

rather than last in the series of recommended projects, because of the much shorter critical power period over which storage would be utilized in the initial system.

Economic Feasibility.—The entire system of power-producing dams by itself was found to be economically feasible even if no multiple-purpose features were introduced. The relationship of this conclusion to inland waterway navigation was immediately apparent. In brief, the lower river dams required

for the power system are also those most effective for navigation. Although a system of dams solely for navigation would be economically unfeasible by a wide margin, navigation benefits are considerably more than the additional annual cost of locks; and the surplus increases the net benefit of the main project. Therefore, navigation features, which had always been desired for the lower Columbia and Snake rivers, were demonstrated to be economically justified in the new system.

The economic feasibility of including flood control was initially considered much more questionable than to include navigation. In view of the immense volume and duration of the Columbia River floods, which have reached a peak of 1,240,000 cu ft per sec, and which last for weeks, general reservoir flood control had not been considered economically feasible, even in conjunction with other uses. A serious Columbia River flood had not occurred since 1894 and there was little public appreciation of a need for general flood control on the main branch of the Columbia River, although a large number of levees had been constructed and held successfully through minor floods.

However, the new power-producing storage reservoirs, even if operated solely for effective power output, would draw down most of the available storage by April 1 in dry years, and a similar drawdown in other years would not reduce prime power. Storage could be refilled during the high water season, which results largely from snow melt, with a crest between May 20 and July 10 each year. Since snow melt and precipitation can be correlated to provide an advance prediction of the approximate volume of such floods, a fairly promising opportunity seemed available for incidental flood control benefits.

After more specific study, it was found that Albeni Falls (Fig. 2) would make no substantial contribution to general flood control because of certain of its hydraulic characteristics; and Grand Coulee, because of its inherent design, would inevitably be filled prior to the arrival of a major flood crest, which would thereafter pass unimpeded over the spillway. Hungry Horse reservoir, which was then about to be built by the USBR, was studied by the USED; it was found that it could contribute materially to Columbia River flood control by increasing its outlet capacity by 50%, which was soon agreed to. Joint-use storage was possible at other projects but the actual attainment of economical flood control was by no means apparent.

Final System Plan.—During the study of general flood control as the final major step in arriving at a balanced plan, the serious May-June, 1948, flood occurred. It added one more to the major floods of the frequency table; it indicated an unexpectedly great amount of damage for a flood of its height; and it dramatically confirmed the assumption that the major floods, such as those prior to 1900, should be expected periodically in the future. Moreover, it changed the public lethargy toward flood control to the demand (more of less as a matter of course) that such a plan be produced, although the final "308" Report was then due in only 4 months, and in spite of the fact that two of the best storage projects had just been dropped because of the objections of local interests.

Anyone familiar with the many details and complications of the planning process will sympathize with the planners at this critical juncture. After

almost five years of continuous study and after eliminating literally 1,000 dam sites from consideration, they were finally left with this short time, much of it required for final editing and reproduction, and with only one new storage project (Hell's Canyon) which could definitely be recommended as contributing materially to flood control. It was fortunate that engineering studies and preliminary plans of such wide scope were available at this time.

The final selection of projects, completed in about three months of intensive work from the date the flood crested, represents no compromise with the basic standards of economic feasibility and confirmed engineering soundness. The first major "break" came when the board of Canadian and American engineers, which had been formed to study the international aspects of the Columbia Basin development, advanced its studies sufficiently to indorse the Libby project (Fig. 2). This project on the Kootenai River, an international tribu-

TABLE 1.—Reservoirs of the Main Control Plan, Columbia River Basin

Item	Reservoir (see Fig. 2)	Status as of July, 1950	Construction cost (thousand dollars)	Usable storage[a] (acre-feet)	Normal head of dam (feet)	Installed capacity (kilowatts)
(1)	(2)	(3)	(4)	(5)	(6)	(7)
1	Hungry Horse	Under construction (USBR)	107,000	2,100,000 (J) 880,000 (P)	485	300,000
2	Glacier View	Alternate to be recommended	94,962	3,160,000 (J)	402	210,000
3	Libby	Authorized (USED)	239,077	4,250,000 (J)	353	588,000
4	Albeni Falls	Authorized (USED)	31,070	1,140,000 (P)	25.5	42,600
5	Grand Coulee	In operation (USBR)[b]	273,000	5,120,000 (J)	348	1,944,000
6	Chief Joseph	Under construction (USED)	225,000	Pondage	170	1,280,000
7	Priest Rapids	Authorized (USED)	326,124	2,100,000 (FC)	146	1,219,000
8	Hell's Canyon	Recommended	342,076	3,280,000 (J)	575	980,000
9	Lower Snake River dams	Authorized (USED)	359,000	Pondage	80 to 100	980,000
10	McNary	Under construction (USED)	227,000	Pondage	90	980,000
11	John Day	Authorized (USED)	379,826	2,000,000 (FC)	95	1,105,000
12	The Dalles	Authorized (USED)	286,286	Pondage	88	980,000
13	Bonneville	In operation (USED)	85,000	Pondage	65	518,000

[a] Abbreviations: "J" denotes joint use of storage; "P" denotes power storage; and "FC" denotes flood control storage. [b] Flood control use recommended.

tary of the Columbia, is unique in its location; there lie in Canada one third of the reservoir and also one third of the intensively cultivated alluvial valley downstream, which was flooded from bluff to bluff by the 1948 flood. Engineering studies of this excellent project were already practically complete. It could be included in the plan without time-consuming surveys, and thus provide more than 4,000,000 acre-ft of usable storage.

Other alternates were reconsidered but, one by one, they had to be regretfully discarded or deferred again because they were too expensive or impracticable. Finally a way was found by the USED to utilize Grand Coulee for flood control, despite its inherent design limitations. This is made possible by providing a total of more than 4,000,000 acre-ft of storage for flood control alone, usable only during major floods, at Priest Rapids and John Day reservoirs, on the lower main stem of the Columbia River. Adding the storage of

Hell's Canyon, almost 7,500,000 acre-ft can be held in reserve during major floods until after Grand Coulee is completely filled. Storage in the lower reservoirs can then be used to eliminate the peak flows and the latter half of the flood. Under this plan, with some relatively inexpensive outlet changes at Grand Coulee, that project can operate with great effectiveness in a reservoir system to control flood damages on the lower Columbia. Flood flows at The Dalles project will be reduced to less than 800,000 cu ft per sec, which can be controlled by levees. In Fig. 2 are shown the reservoirs authorized as of June, 1950, the projects recommended since that time, and the principal alternates studied.

Major reservoirs operated in this general flood control plan, listed in Table 1, will have 22,010,000 acre-ft of effective storage usable for general flood control as a primary purpose. In addition, Albeni Falls and the upper and central

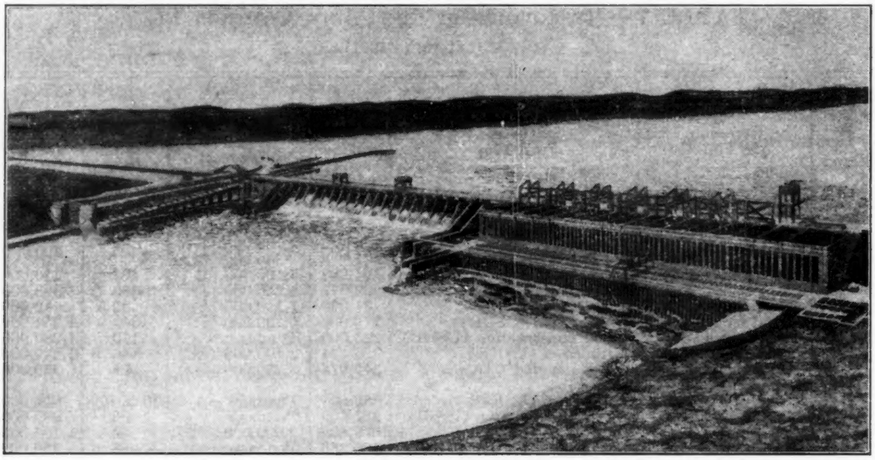

Fig. 8.—McNary Dam, on the Columbia River

Snake River Valley projects, at times, will have important general flood control effects incidental to their operation for subbasin and power purposes. Their storage will total more than 5,000,000 acre-ft in addition to the 22,010,000 acre-ft.

Main Projects.—In the Columbia River system, the principal projects, called the Main Control Plan, include the existing major dams, Grand Coulee and Bonneville; the three under construction (August, 1950)—McNary, Hungry Horse, and Chief Joseph; the previously authorized lower Snake River dams; and other recommended projects (all described in Table 1).

These projects are all of large size, particularly as to installed hydroelectric capacity. The three great projects, Bonneville, Grand Coulee, and McNary, which were once considered as isolated "super-projects," now fall into their proper perspective, as units of the same order of magnitude as the remainder of the system. One of the largest projects is shown in Fig. 8.

In introducing flood control into the extremely effective hydroelectric power system of the preliminary plan, really careful study had to be given to

the effect on power output. For example, when considered individually, the drawing down of Grand Coulee, in order to vacate the desired flood control storage, would reduce its peak power output by more than 500,000 kw from that otherwise obtainable at full pool. It was at first thought that reliable flood control on the Columbia River would be obtainable only by major sacrifices in power output. It was found, however, that, on a system basis, practically no sacrifice of firm power need be entailed since the higher run-of-the-river dams can provide surplus capacity at such times if plans are properly coordinated.

III. System Structure

From an engineering point of view, the power from these new dams (which are few in number but large in size) will presumably be distributed by interconnected power grids connecting all parts of the Pacific Northwest with Canada, California, and other near-by areas. Such a grid system is already well under way. The electrical interconnection of seven private and two municipal utility systems with the Bonneville Power Administration transmission system forms the Northwest Power Pool, which includes all major electrical utilities in Utah, Montana, Idaho, Washington, and most of Oregon.[2] The entirely voluntary joint operation of this system has increased the maximum reliable firm power output which the members could reliably produce individually by 300,000 kw in the aggregate, or 18%. Technical coordination of the system has been good and is creditable to all concerned.

The system now (1949) consists of eighty-eight electrical generating plants, of which seventeen are steam. Already there are electrical connections and technical coordination with systems outside the power pool. The increase in the number of federal generating plants to a total of thirty four, including the minor dams in the Willamette and Snake valleys, will represent an increase of not much more than one third in the number of plants involved, although the total output of the system will be more than tripled. By the time this stage occurs, it appears probable that all electric systems on the Pacific Coast and in western Canada will be interconnected and closely coordinated, with additional connections to still other areas. The Northwest Power Pool already covers a market area much more extensive than the Columbia Basin, but coincidence of power market areas with drainage basin boundaries is not generally found now and will be still less characteristic of the future. Some policy questions in the power distribution field remain to be resolved, but the practicality and utility of a backbone distribution network, interconnecting private as well as public systems over a wide market area, appear to be established incontrovertibly.

As a second conclusion regarding system structure, certain major subbasins can be set aside for multiple-purpose development mainly in accordance with subbasin needs. The Willamette Basin is an outstanding example. Comprehensive planning for the entire Columbia Basin has resulted in developing a multiple-purpose plan for the Willamette Basin, the initial projects of which are already constructed; but this subbasin plan will have little operating relation-

[2] *Civil Engineering*, August, 1948, p. 20.

ship with problems of the Columbia River Valley, other than the exchange of waterborne commerce between the two rivers at Portland, Ore., the sale of power through a common transmission network, and the conduct of flood fights in the Portland area. Flows from the Willamette River are downstream from all Columbia River reservoirs and cannot affect them, and floods on the Willamette River occur at such times that they contribute only infrequently to the Columbia River floods. The projects in this subbasin should be operated in accordance with a carefully integrated plan, primarily for subbasin needs, especially flood control.

A similar situation prevails generally as regards the Snake River Valley in southern Idaho and Wyoming. Here irrigation is of primary importance, and the main Columbia flood control plan has been so developed that irregularities in controlled flood flows resulting from irrigation storage at Idaho and Wyoming can be fully ironed out by other main stem storage above the main areas of flood damage. Any suggestion that the valuable waters of the Snake River be disposed of for any consideration other than the direct needs of the Snake River Valley would be unacceptable to the upstream states concerned. Other uses have not been requested by downstream states and are unnecessary for the development of the basin as a whole under plans outlined in this paper.

The large present and future irrigation depletions in certain areas of the Columbia Basin have only a minor influence on the discharge of the lower Snake River and the main stem of the Columbia River. Plans for constructing and operating projects in the upper Snake River and other similar areas can be based on subbasin needs without detriment to the optimum development of the Columbia River system as a whole. Similarly, many other subbasin and local projects, including all levee and channel improvements, navigation features of dams, and the proposed irrigation developments throughout the basin can be localized for operation, or operated in accordance with specialized functional control.

The relationship between irrigation pumping and firm power output is of comparatively little importance now but will be of increasing significance as future irrigation plans for the Columbia Basin are developed. As far as presently authorized and recommended projects are concerned, there is no substantial conflict. Even under severest drought conditions prime power from projects previously authorized would not be reduced by irrigation pumping needs because the critical storage period extends only from October through April. In the recommended comprehensive plan, it is recognized that an occasional conflict will occur not so much because of an increase in irrigation storage pumping as by the extension of the critical storage period.

In May, August, and September of very dry years prime energy must be taken to maintain the irrigation pumping load, although the frequency of such occurrences will not be great. However, the very large potential extensions of pump irrigation to be ultimetely included in future projects, not yet recommended for immediate construction, will cause much larger use of prime power for irrigation with a frequency that cannot be disregarded. For such projects, it will become impossible to base irrigation pumping any longer on purely secondary power at nominal cost. As far as the present plan is concerned,

however, the irrigation pumping loads, superimposed on the lower power requirements for other purposes, will balance fairly closely with the available system energy, including available secondary energy in dry years.

IV. Flood Control and Power Operations

The only part of the plan where requirements are difficult to resolve, from an operational point of view, lies in the joint use of the major reservoirs for power output and Columbia River flood control purposes. The operating plan to be outlined here has been developed far enough to demonstrate the practicality of reliable flood control and the general lines of an operating plan. Refinements will be made as the system is constructed and more data become available for forecasts.

Seven main reservoirs, with a usable joint storage capacity of 22,010,000 acre-ft, are designed for main stem Columbia River flood control. Operated during most of the year mainly for power purposes, they must be capable of insuring reliable control of floods, of magnitudes up to 1,240,000 cu ft per sec at The Dalles, which ordinarily occur with a peak between May 20 and July 10. Other reservoirs will contribute incidentally to the control of major floods, but will be operated for other primary purposes. Most reliance must be placed on these seven reservoirs to reduce all main Columbia River floods to flows that can be contained by practicable levees.

During the fall and winter months the flood control plan will not require reservation of storage primarily for flood control except at John Day and Priest Rapids, where emergency flood control storage will always be kept available. By April 1 all joint-use storage will be available, except at Grand Coulee where only 3,000,000 of the 5,100,000 would be drawn down. Such drawdowns, of course, would be made by operating-rule curves, such as those shown in Fig. 9, through normal operating procedures. As long as the drawdown is effected by April 1, the flood control criterion will be met and operation up to that date can consider primarily power output.

Operation after April 1 will be in accordance with an initial flood forecast. This forecast will be generally similar to those made for the mainstem Columbia River by the United States Weather Bureau, the Soil Conservation Service (United States Department of Agriculture), and the USED, but an expanded meteorological network will be required.

Although floods on the Columbia River can be predicted much more accurately than those of most major rivers, there will remain certain inherent potential errors in the forecast. Columbia River floods occur primarily from melting of the snow pack, the water content of which is measurable with great accuracy if sufficient stations are installed. There is a normal relationship between the water content of snow on the ground and the peak flood discharge, depending on the usual temperature sequences and a normal amount of spring precipitation; and variations from this relationship are usually quite small. However, the greater floods are likely to be caused by a combination of events in which a heavy snow pack is exposed to unusually cold weather during April and May, and to heavy rains in May, accompanied by sudden prolonged warm weather. A further major factor is a retardation in the normally earlier

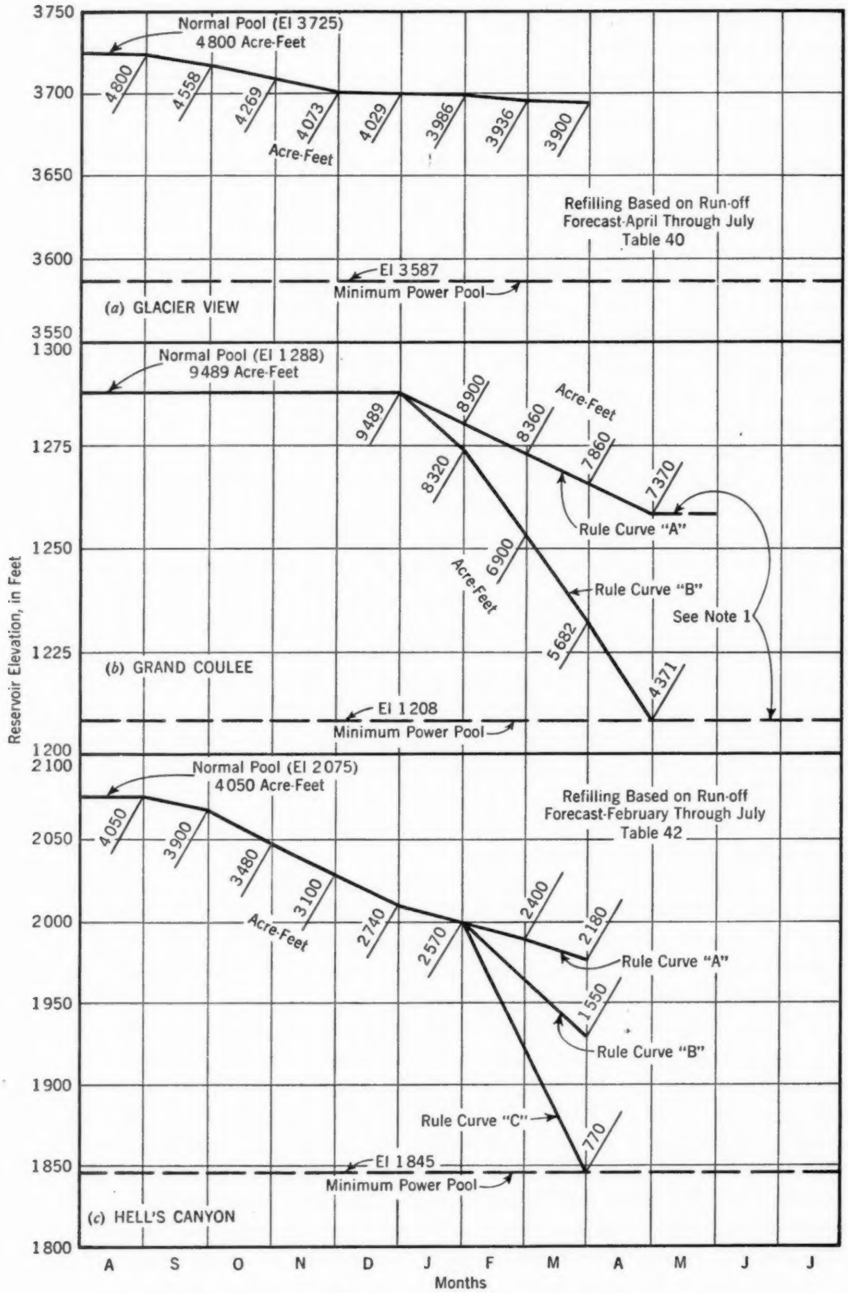

FIG. 9.—OPERATING-RULE CURVES FOR POWER AND FLOOD RESERVATION; PHASE C DEVELOPMENT, COLUMBIA RIVER AND TRIBUTARIES

flood runoff of the Snake River, resulting in a coincidence of flood peak with that of the upper Columbia.

These factors may cause very unusual deviations from the norm, on the side of danger. Such deviations do not occur in accordance with unweighted frequency curves but are most likely to occur during years of great floods, toward which they are a contributing factor. Although the data are insufficient for accurate correlation, the fact that such conditions occurred during 1894 and 1948 (the only two very large floods of which there is accurate knowledge) indicates the necessity of allowing a sufficient safety factor to provide for such "unusual" occurrences during any major floods, despite the increase in forecast reliability expected in the future.

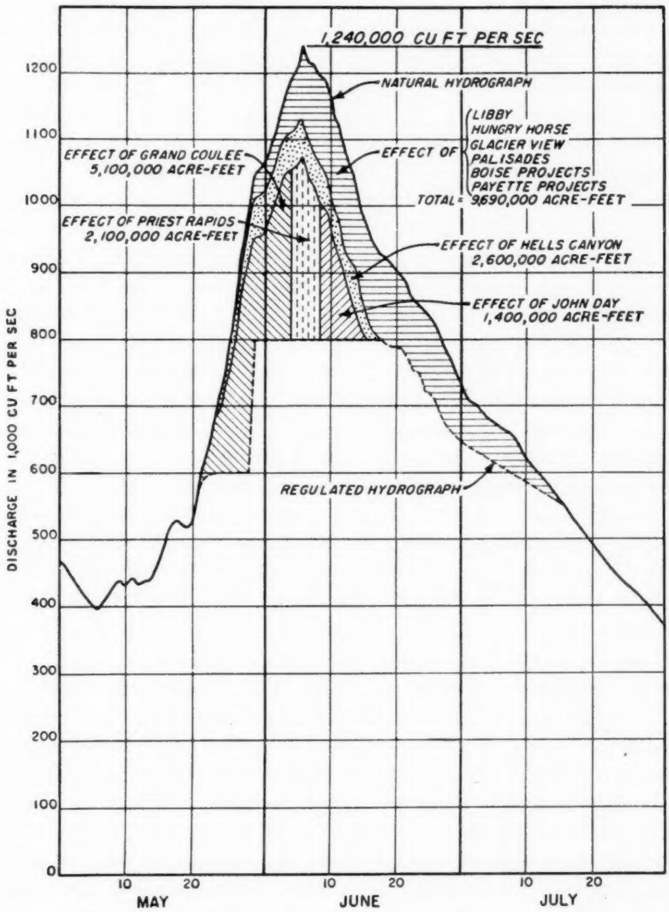

Fig. 10.—Hydrograph of the 1894 Flood, Regulated by the Main Control Plan: Columbia River at The Dalles, Ore.

If the forecast on April 1 is for a flood of 665,000 cu ft per sec or more, all available joint-use storage will be held empty, and Grand Coulee (initially

providing 3,000,000 acre-ft of storage) will be further drawn down to provide its full 5,100,000 acre-ft by May 1. This system storage is adequate to control a repetition of the 1894 flood, with an operating margin of 2,900,000 acre-ft to allow for possible inaccuracies in reservoir operation and discharge data during early flood stages. Fig. 10 illustrates results of applying these procedures in the case of the 1894 flood.

The system storage to be provided is so great that, if the 1894 flood were repeated, with all reservoirs drawn down, and with use of the aforementioned operating margin, more than 6,000,000 acre-ft of storage would remain unused at the end of the flood. Excess storage probably not worth reserving for flood control use would remain at Hungry Horse and Glacier View, and on the Boise and Payette rivers (where main stem flood control is only incidental). A usable reserve of 600,000 acre-ft would remain at John Day.

During years of drought, which constitute the critical power period, there is no need to hold all these great reservoirs empty. When the prediction on April 1 is that the peak discharge will not exceed 450,000 cu ft per sec (about one year in four), all joint-use storage will be allowed to be filled as rapidly as power production requires. The levee capacity to hold flows of 800,000 sec-ft, plus the reserve capacity available in the two lower river reservoirs, is ample protection against any flood that may occur. On May 1, another prediction will be made. When floods with peaks greater than 750,000 cu ft per sec are anticipated, all storage will be held down until the flood arrives. If a flood between 465,000 cu ft per sec and 750,000 cu ft per sec is anticipated, proportionate reservations of joint-use storage will be made.

In the later stages of floods, minor deviations and inequalities will develop, particularly as a result of unanticipated discharges from minor tributaries, such as the Yakima, and the time elapsing before releases in the upper Flathead and the Kootenai arrive in the lower Columbia. However, Hell's Canyon and Grand Coulee will eliminate most of these irregularities, and Priest Rapids and John Day can handle the remainder. For example, an unexpected discharge of 50,000 cu ft per sec extra from the Yakima River, menacing the levees on the lower Columbia, could be balanced by the retention of storage for 48 hours in the Priest Rapids reservoir, amounting to 200,000 acre-ft, or 10% of its capacity. Meanwhile a faster rate of storage in Grand Coulee or Hell's Canyon could become effective and thus allow the quick release of storage in Priest Rapids prior to the arrival of other unexpected crests.

During actual passage of a major flood, day-to-day releases and even hour-to-hour releases from at least the four lowest storage reservoirs must be controlled by one operating center. Because of the paramount importance of flood control at such a time, and the necessity for quick action, truly unified control with full authority and responsibility is highly desirable. For this part of the system, ordinary coordination at such times might not be sufficient.

As regards power production during a flood, the seven major storage reservoirs can continue to have their normal operating relationships with the much more numerous municipal and private power projects comprising the balance of the Northwest Power Pool. Rapid changes in head and unusual amounts of drift during the flood will entail operating problems rather more

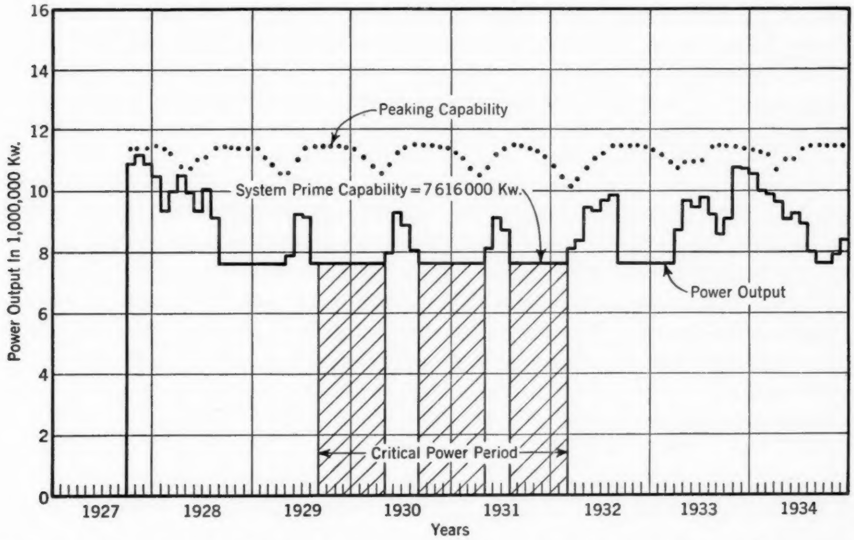

FIG. 11.—POWER OUTPUT AND PEAKING CAPABILITY; PHASE C SYSTEM, COLUMBIA RIVER AND TRIBUTARIES

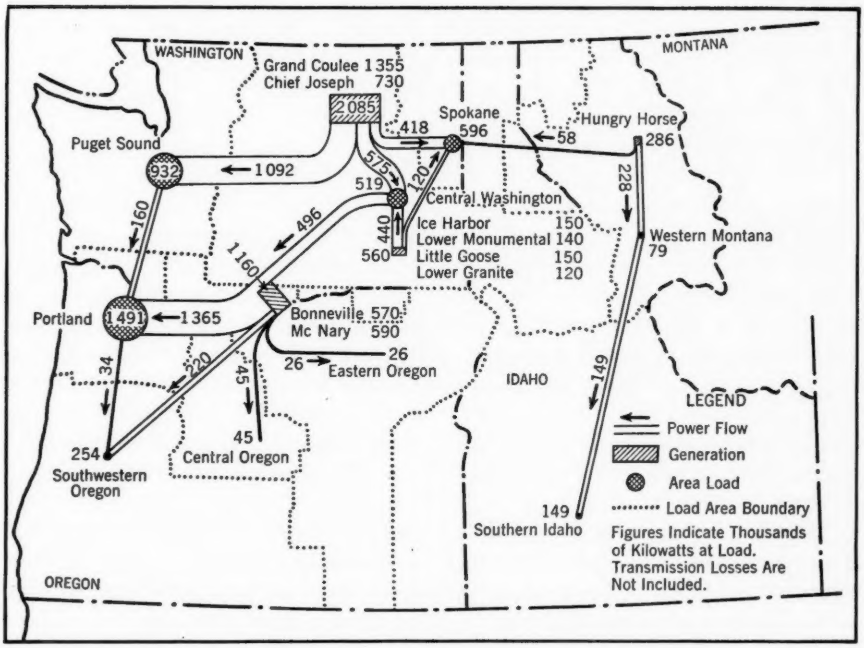

FIG. 12.—POWER FLOWS AT THE TIME OF THE DECEMBER PEAK LOAD
(FIRM POWER FROM PRESENT AND AUTHORIZED PLANTS)

difficult than those normally faced, but similar in kind. Except in the very largest floods (even larger than that of 1948) there need be no directly conflicting interest between flood control and power except as regards production of secondary power; and at such times flood control operation should have overriding priority, subject only to emergency provisions to assure safety of each structure, if reliable flood control is to be obtained.

Power Output.—The operating-rule curves proposed would be modified by additional experience; but they appear to present no real difficulty in reconciling interests of flood control and power. System capability during an assumed critical drought period of the future and a system flow chart for major groups of projects and, as recommended, are shown in Figs. 11 and 12. Only secondary energy is sacrificed by this plan for flood control operations of Main Control Plan reservoirs; and this secondary energy, on account of the small proportion of thermal power output in the region, has been assumed to be of no value in determining economic benefits.

V. Associated Plans of Other Agencies

Transmission System.—In the Columbia Basin, although the USBR markets power to a limited extent, the main distribution and marketing agency for federal power is the Bonneville Power Administration. For projects included in the "308" Report, the Bonneville Power Administration made plans and cost estimates for a transmission system which would distribute power from the projects, link all public and private utilities in the region, and connect by interregional ties with four other major power areas, including western Canada. The scope of this proposed network may be visualized from the estimated first cost of $462,000,000. Costs of this extensive system were included in studying the economics of the Main Control Plan.

Lower Columbia River Fisheries Plan.—The Columbia River poses a unique problem in that it is necessary to conserve great runs of salmon while developing the stream for other purposes. The salmon spawn in bars of main rivers and tributary streams, the young fingerlings swim down to the sea, and 4 to 6 years later the mature fish return to repeat the cycle. Many natural spawning grounds have been completely blocked over a period of years by dams built without proper provision for passage of the fish; and overfishing and pollution of waters have contributed to reduce the original runs. In 1938 the Bonneville Dam was constructed, with elaborate and well-designed fish-passing devices which have proved highly successful. In the case of McNary Dam, the fish-passing devices will cost $14,000,000 and will incorporate improvements over those at Bonneville.

However, since there is undoubtedly some cumulative adverse effect of a large number of dams, even when carefully designed to aid passage of fish, the comprehensive plan calls for a compensatory program of $20,000,000, known as the Lower Columbia Fisheries Plan, to clear natural obstacles from lower tributary streams and to build hatcheries. This plan was developed by the Fish and Wildlife Service. Although the plan as a whole has not yet been authorized by Congress, some money has already been appropriated, and the

State of Washington has taken legislative action to prevent encroachment upon the streams concerned in that state.

Watershed Improvement Plans.—The programs of soil conservation and reforestation are of great importance in their own right, in addition to their effect on floods and runoff. In the Columbia Basin, as elsewhere, they aid flood control and general water conservation. Although the great floods of 1876 and 1894 in this watershed, before forests were generally cut over, are ample warning that such floods are not basically man made, there is no doubt that in certain local areas, improper farming and cutting or overgrazing of natural cover have contributed to the flood problem and increased the silt carried in streams. In certain parts of the Willamette watershed, and (even more strikingly) in the Walla Walla, Touchet, and other loessal areas, flood control by reservoirs and channel works must be very closely integrated with plans for watershed treatment.

Fortunately, the sediment content of the main Columbia River is relatively low; and the same problems are not so acute for the major reservoirs. However, if the present soil and forest cover loses capacity to absorb runoff, so that when the most severe climatic conditions recur they produce larger floods than previously, it will be necessary to provide additional reservoir storage to compensate. To this extent the over-all plans for reservoir flood control and for improvement of soil and forest cover are complementary.

Financing Irrigation Development.—In the later stages of preparing the comprehensive plan a basic lack of economic balance was noted in certain important benefits. In particular, practically all the irrigation potentiality lies east of the Cascades, whereas more than two thirds of all the potential power demand in the Northwest is expected to develop in the area west of the Cascades. Although the plan contained liberal provisions for expansion of irrigation, based mainly on USBR plans, great difficulty had been found in financing such projects.

Water users have generally been able to repay only a part of the irrigation costs. Most potential irrigation is physically widely separated from the power-producing projects; and the inclusion of irrigation projects as a part of a "comprehensive plan" would not invalidate general provisions of law requiring repayment. The Portland and Puget Sound areas, which use most of the power, are also interested in irrigation development, because the irrigable areas of the "Inland Empire" will form a great addition to the trade hinterland of the port cities.

As one solution, it was suggested in the division engineer's report that a small amount, which would be immaterial to the average power user, be added to power rates in the Northwest in order to cover irrigation costs not chargeable to water users. Subsequently, as part of an agreement signed on April 11, 1949, the secretaries of the Army and the Interior agreed to recommend to Congress that financial assistance from all power revenue producing projects in the Pacific Northwest should be pooled and utilized to aid irrigation under principles consistent with those embodied in reclamation law. The cost of recommended irrigation development was found to be relatively small compared to anticipated power revenues.

VI. General Considerations

As has been indicated, the comprehensive planning process has as its major objective the delineation of general basin-wide plans and criteria. These are not general ideas or principles but highly specific engineering conclusions and relationships which vary in accordance with the stage of development. The main concept or structure of the optimum basin plan and the degree of integration necessary for operational control cannot be predetermined from general principles but are empirically derived from engineering relationships and physical and economic conditions. If the comprehensive planning process is omitted or incomplete it is likely that serious mistakes will be made, not only by developing projects in the wrong priority but, more seriously, by adopting conflicting or overlapping plans, or by basic deficiencies in project design impossible to detect other than by a basin-wide, multifunctional approach.

Once a comprehensive plan has been developed, many more detailed supplementary plans can be prepared within its terms of reference; and these plans can often be approached on the basis of local or unifunctional needs, and properly coordinated with the main plan. When sound plans are made, it does not necessarily follow that the geographical basis for construction, operation, and maintenance will be the same as for planning.

Construction is always best decentralized; distribution of electrical power is usually best accomplished through the widest possible interconnected system, not related to watershed boundaries; and project operation may be best centralized into a single basin-wide system, decentralized into subbasin components, separated into functional groupings, or operated as a combination of the three, depending on actual conditions. Review of plans on a comprehensive basis will be necessary from time to time as conditions change and new techniques are evolved.

As regards many other aspects of national resource development, Congressional policies are implemented throughout the United States, so that, as regards each function, such as irrigation, flood control, and soil conservation, similar procedures are applied in adjacent major watersheds. This is true in technical as well as administrative matters.

Important specific problems sometimes arise concerning interbasin waterways or diversions. Although possibilities are physically limited, new proposals, advanced from time to time, are often the occasion for serious conflicts of interest between the respective localities and interests concerned. When such problems arise the approach must be shifted to a broader geographical basis, including the entire area concerned, at least for the period of the investigation.

It is a major task of comprehensive planners to minimize possible conflicts of interest and provide a system with optimum public benefits. Ordinarily separate storage must be provided for power and flood control in order for both to be fully reliable. It is only where fairly accurate flood predictions are possible that true joint-use storage can be developed. The same is true in cases of joint-use storage for flood control and irrigation. Moreover, the requirement that the irrigable land must be located so that it can be served from the

controlling reservoir often precludes successful development of irrigation in multiple-purpose projects.

Where the heads of dams are not too great, navigation use of reservoirs can usually be provided without material detriment to other purposes. There is often a potential conflict between water supply for irrigation purposes and for other downstream uses; and in the Columbia Basin it is possible to avoid such a major difficulty only by careful planning to provide adequate storage intermediate between the major areas concerned, and a properly balanced general operation plan.

On the Columbia River with its numerous possibilities for power production exceeding 30,000,000 kw in the ultimate, certain general results were obtained which might not be so apparent in lesser water sheds. First, the large projects proved generally to be more economical sources of hydroelectric power than the small projects, and the balanced series of dams, more economical than a number of projects on separate tributaries. For various cases, especially railroad and community relocations, and because of the necessity of restricted heights for passage of anadromous fish, projects often could not be planned to the full size which would otherwise have been most economical. All studies on the replacement of large dams by a greater number of small dams showed an increase in cost, usually very material. Also, despite criticism of the amounts of valley land required by large reservoirs, systems of small reservoirs with the same effective storage required much greater land areas.

With few exceptions, multiple-purpose use of major reservoirs gave the maximum benefits and best all-around plan. However, the optimum combination of functions varied widely.

Although the most economical sites are obviously generally developed first, the entire system of reservoirs is much more effective from an engineering point of view than individual reservoirs separately. Power from the complete system, it is estimated, need be sold at only about 25% more per kw-yr to repay costs, as compared to present rates for Bonneville and Grand Coulee power, although unit construction costs have doubled since those projects were built. This favorable result is possible only because of a reservoir system wherein head and storage development and multiple-purpose use are exceptionally well balanced.

New head developments on the main stem can advantageously be added to the system as long as sites remain. On the other hand, storage developments confer system benefits in accordance with a law of rapidly diminishing returns, initially very advantageous, if sufficient head is developed downstream, but with much less return from later projects.

Lastly, experience at Bonneville and Grand Coulee has proved that properly conceived projects in the Northwest can produce power at very low rates and can make an important contribution to the regional economy, at the same time returning to the United States Treasury a surplus over and above all power costs. Such a combination of effective engineering, fiscal and economic soundness, and general public benefit is the end to be sought in comprehensive water resource development.

PROCEEDINGS OF THE SOCIETY

SYDNEY WILMOT
Manager of Technical Publications

HAROLD T. LARSEN
Editor of Technical Publications
